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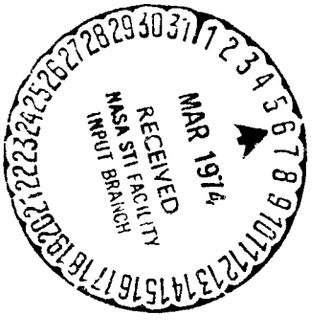

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THE DESIGN AND CONSTRUCTION OF AN ANECHOIC CHAMBER LINED WITH PANELS FOR INVESTIGATION OF AERODYNAMIC NOISE

J. P. Berhault, M. Sunyach, H. Arbey and
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1. INTRODUCTION

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Numerous practical cases of noise produced by turbulent flows have been studied by the fluid mechanics laboratory of the E.C.L. This is why we built an anechoic chamber containing an aerodynamic circuit. This had a free test section inside the chamber (Figure 1). The installation can be used to carry out tests on jet noise and on the noise from obstacles placed in the flow. Also this anechoic chamber complements the acoustic equipment in the laboratory, that is: /70

- two coupled reverberating chambers (Figure 1) with the following average dimensions: L = 6.50 m. l = 4.50m, H = 4.45 m and L = 6.40 m, l = 4.50 m, H = 4.45 m. The central opening is 3.45 m x 2.40 m; the reverberation time is 9.2 seconds at 500 Hz.

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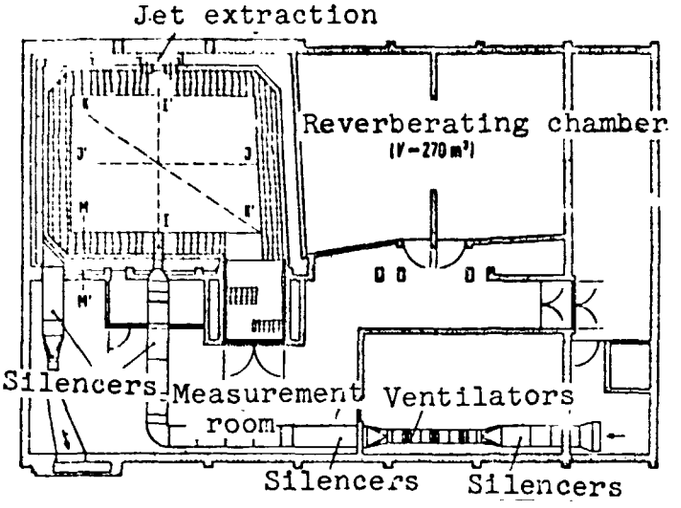

Figure 1. General view of the aero-acoustical laboratory

- a reverberating chamber with the following average dimensions: L = 9.35 m, l = 6.45 m, H = 4.45 m with a reverberation time of 11.5 seconds at 500 Hz. It has an air inlet for which the conduit has an acoustical treatment (glass wool cover and rejecting filter tuned at the frequency of the supply ventilator blades). This installation has a maximum flow rate of 1.5 m^3/sec (pressure 500 Pa) and is presently being used for aerodynamic and acoustical studies of blower nozzles.

2. CROSS SECTION AND ENVIRONMENT IN THE CHAMBER

The anechoic chamber is located in the basement of a two-story building constructed on a new site of the E.C.L. at Ecully, away from any heavy traffic road. The operation of the apparatus located in the building produces an acoustic pressure level through a 1/3 octave filter of 45 dB in the basement ($2 \times 10^{-5} N/m^2$ reference), for frequencies less than 200 Hz and 25 dB for frequencies above 200 Hz. The main source of the environmental noise in the chamber is the ventilation complex of the aerodynamic circuit connected with the chamber (Figure 1).

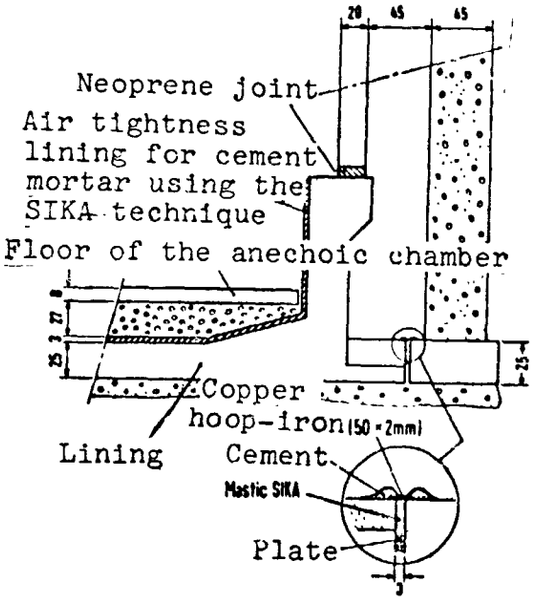

Figure 2. Detail of the cross section of the chamber (sides in cm)

Section 8 discusses the location of this unit and its acoustical insulation.

The design of the chamber follows the technique of a double enclosure (Figures 1 and 2). The walls and the ceiling of the interior enclosure form a bell which rests on a water-resistant lining, through the intermediary of a 1 cm thick neoprene joint. The lining has an independent foundation from that of the building. It is sealed off by means of a joint with a small rigidity (Figure 2). The floor of the chamber consists of tile insulated from the lining by a gravel bed. The mechanical vibration insulation of the interior enclosure with respect to the measurement room adjacent to it is about 55 dB. These measurements are carried out with a Bruel and Kjaer 4318 accelerometer connected with a Bruel and Kjaer 2624 amplifier. It is located at 12 positions distributed over the interior walls of the chamber. The excitation is provided by a Bruel and Kjaer 3204 striking machine located 50 cm from the exterior wall. /71

The chamber is made of coarse masonry and has the following dimensions: length 7.70 m, width 6.20 m, height 5.40 m. The floor and the ceiling are parallel as are the large lateral walls. The small lateral walls make an angle of about 5°.

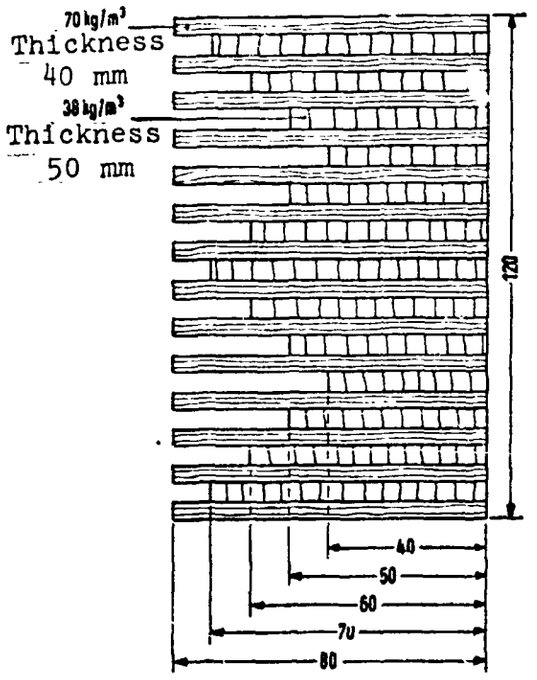

Figure 3. Cross section through the covering used (sides in cm)

3. INTERIOR COVERING OF THE CHAMBER

Because of the small dimensions of the chamber caused by the architecture of the building, we wanted to have an interior covering which would be very efficient and which would restrict the remaining available space as little as possible.

The covering utilized consists of an alternate series of glass wool panels, with the mass densities of 70 kg/m^3 and 38 kg/m^3 (Figure 3). The densest panels are 80 cm long. The less dense panels have a length of 40, 50, 60 or 70 cm. This covering was chosen because of results obtained on new absorbant configurations established by the company, Saint-Gobain (Centre de Recherches Industrielles de Rantigny). They make tests in a stationary wave tube with a cross section of 1.20 m x 1.20 m and a length of 11.3 m. For any given configuration, the variation as a function of frequency of the absorption coefficient is shown in Figure 4 for conditions of normal incidence.

The square mesh with a side length of 1.20 m was retained as a basic element for covering the chamber. The meshes are horizontal and vertical in an alternating fashion (Figure 5 (a)). On the floor and on the ceiling, the panels are simply placed

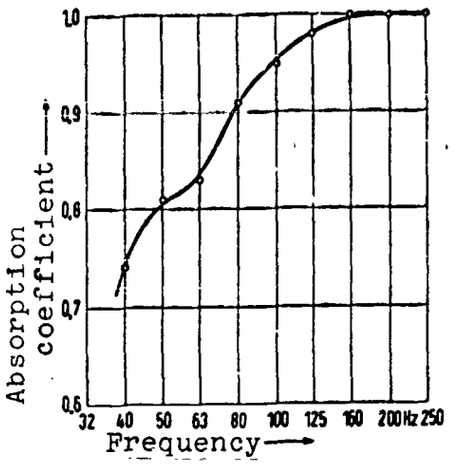

Figure 4. Absorption coefficient of the covering used, at normal incidence

next to each other. On the ceiling, they are intertwined with plastic tubes (80 mm diameter) which are suspended from the concrete by collars. A polyester sheet with a thickness of 3/10 mm separates the concrete and the panels. There are no resonating cavities associated with the covering. It is known that increases in the reflection coefficient can appear sometimes when the frequency equals the resonating frequency. This means that the operation of the chamber at low frequencies is compromised [1, 2]. /72

Compared with generally used absorbing configurations [1-7], the covering used consists of a very simple design and has the following two properties:

- mass reaction of the glass wool at low frequencies,

- flexible connection between the glass wool and the walls

These properties have found to be essential in subsequent work, [5, 8].

4. INLET LOCK

The anechoic chamber is entered through a lock with a door (Figure 1). The ceiling and the lateral walls of the lock consist of two 20 cm thick walls (filled stone blocks connected by a

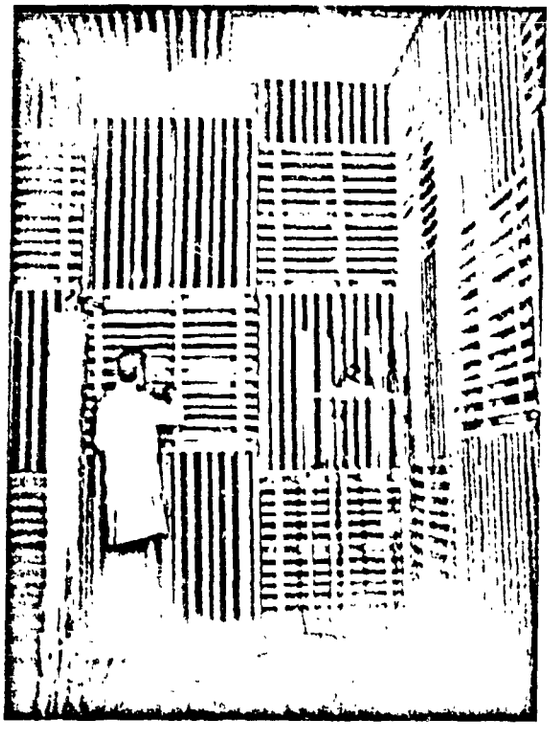

Figure 5. (a) Overall view of the chamber and location of the source and microphone during the anechoic tests

continuous mortar bed) and separated by a 30 cm space. The interior of the lock, which has a height of 2.14 m, consists of the following:

- two glass wool baffles (length: 1.20 m, thickness 60 and and 40 cm, mass density 70 and 38 kg/m^3),
- a 5 cm glass wool layer 38 kg/m^3 on the walls and on the ceiling, as well as on the internal side of the lock door,
- carpeting on the floor.

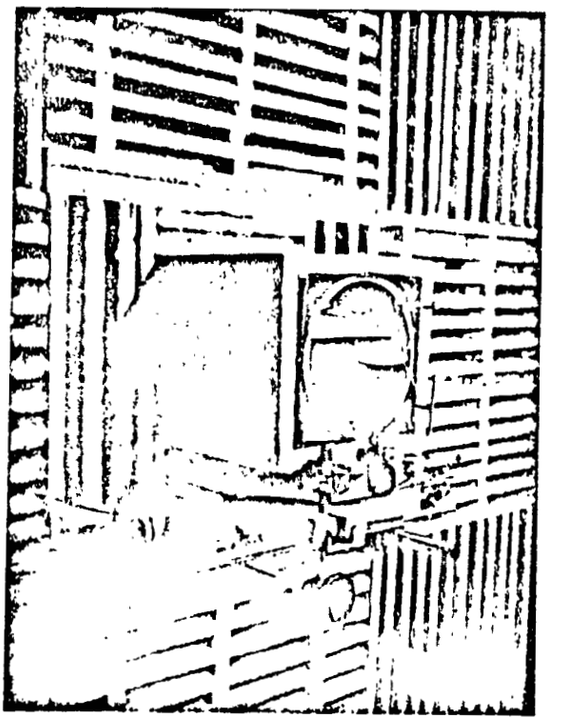

Figure 5. (b) Outlet nozzle of the aerodynamic circuit associated with the chamber and mounting installation for studying the noise from obstacles

In this way, the lock has absorption characteristics which are close to those of the chamber (see Section 7).

The lock door (width: .30 m, height 2.10 m) has two leaves and it is operated manually with a casement bolt which is accessible from inside or outside of the chamber. Each leaf consists of two 3.6 mm steel plates separated by an approximately 10 cm base. There are steel stiffening members and gypsum panels. The door frame is also made of 3.6 mm steel and is sealed to the walls. The door has an average approximate attenuation of 45 dB between 125 Hz and 2 kHz. This attenuation is comparable with the attenuation of the double wall construction of the chamber and the lock.

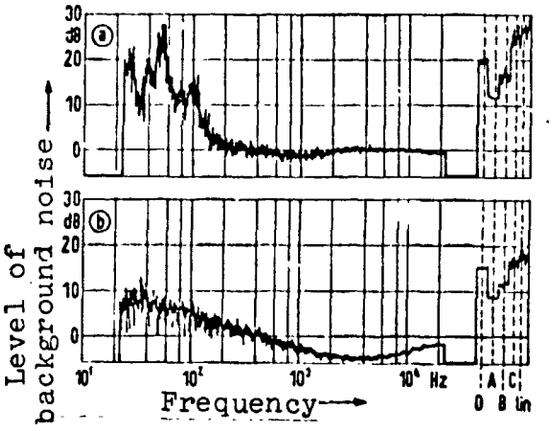

Figure 6.

(a) Background noise of the chamber
(b) Measurement circuit background noise

The cables used for commands and measurements pass along the path MM' through the double wall of the chamber (12 cm diameter orifice), as well as the shielded wires which supply the lighting for the chamber (incandescent lamps).

5. FIXTURES IN THE CHAMBER

The accessible part of the chamber was limited to a 0.50 m round opening and a central 1.20 m x 1.20 m platform. The floor which consists of blocks framed in angle iron can be completely removed, so that possible parasitic reflections can be minimized [9].

The angle irons have the dimensions of 20 mm x 40 mm for the round opening and 80 mm x 80 mm for the central platform. They are covered with a layer of adhesive polyester foam and rest on supports embedded in concrete and immersed in the glass wool (20 mm round steel members or 80 mm x 80 mm angle iron).

There are a few additional supports (diameter 80 mm) between the lock and the central platform. They can accept rails to help the placement of the equipment on the central platform (permissible load 10,000 N).

6. CHAMBER BACKGROUND NOISE /73

The measurements were carried out with a Bruel and Kjaer chain which consists of a 4145 microphone with a diameter of 2.54 cm, a 2619 preamplifier, a 1/3 octave analyzer 2113 and a 2305 level recorder. Figure 6 shows the spectrum and the acoustic levels obtained (decibels D, A, B, C and linear scale from 20 to 20,000 Hz) when the microphone is placed in the center of the chamber. For comparison purposes, we also show the signal corresponding to the electronic noise of the measurement chain, for the case where the preamplifier was terminated by a 50 pF capacitor. The noise of the chamber itself therefore only essentially appears at frequencies less than 100 Hz. This contribution depends somewhat on the location of the microphone within the chamber. For example, the 50 and 100 Hz peaks disappear near the longest wall of the reverberating chambers. The 100 Hz peak is accentuated (+ 4 dB) next to the lock and next to the reverberating chambers.

7. ANECHOIC TESTS

7.1 Execution of the tests

In order to determine the approximation with which propagation conditions in free space are simulated, we systematically measured acoustic pressure p decrease as a function of distance r to the source. For these measurements, the blocks are removed from the chamber.

We used the following sources:

1) An electrodynamic Supravox T 215 RTF 64 loudspeaker with a diameter of 21.5 cm installed in an enclosure with dimensions of 50 cm x 50 cm x 50 cm which had a decompressior slot

2) Two Audax F11PA9 loudspeakers with diameters of 10 cm facing each other and connected so that they would be excited in phase

3) A Audax 5CIS/C electrodynamic loudspeaker with a diameter of 52 mm, installed in a baffle made up of glass wool panels.

In each case, we performed the tests over the entire permitted passband. We will only report on the results obtained with source No. 1 for frequencies less than 800 Hz and on experiments with source No. 2 for higher frequencies. We found that for most tests carried out in the range between 1 to 6 kHz, source No. 3 gave much better results than those which corresponded to source No. 2. This is probably because of the more directional nature of this third type of mounting.

These sources were excited with pure frequencies (Tacussel GBF4 generator and Tacussel AP12 power amplifier). A Bruel and Kjaer capacitive type 4145 microphone with a diameter of 2.54 cm was mounted on its 2619 preamplifier and was used for measuring the acoustic pressures. It is attached to a mat with a diameter of 4 cm and attached to a carriage frame. This unit is covered with 5 cm of glass wool and is displaced along a track made of two duralumin profiles 25 mm thick. They are separated by 50 cm with small wooden transverse members. This track rests on the interior covering of the echo chamber and on

angle iron members which also support the block. This is done with glass wool wedges (Figure 5 a). The carriage is displaced within the measurement room by a pulley system and a nylon cord. Its position is determined by the rotation of a drum, which is translated into a voltage by means of a multi-winding potentiometer.

The microphone signal is transmitted to a wide band Bruel and Kjaer type 2107 analyzer ($\Delta N/N = 6\%$). The voltage at the terminals of the moving frame is then applied to the amplifier Y of a XY Hewlett-Packard 7005 B recorder. The voltage across the potentiometer terminal measures the position of the microphone and is applied to the X amplifier. For these recordings, the position of the microphone is measured with respect to the front plane of the loudspeakers (source No. 1 and No. 3) or with respect to the median plane (source No. 2). The measurements of the acoustic pressure levels are carried out on a scale of 10 dB (Figure 7). By doing this, the accuracy obtained for direct reading of the acoustic level with the measurement chain can be maintained on the recording. The reproducibility of the tests (±0.2 dB, ± 0.25 cm) confirms the stationary character of the recorded level variations. /74

The results are then translated onto a logarithmic diagram (Figure 8). The real position of the source can be determined, which is then the position assumed as the origin for the source-microphone r parameter. These corrections are always less than 5 cm, such that their influence on the measurements is negligible above 1 m.

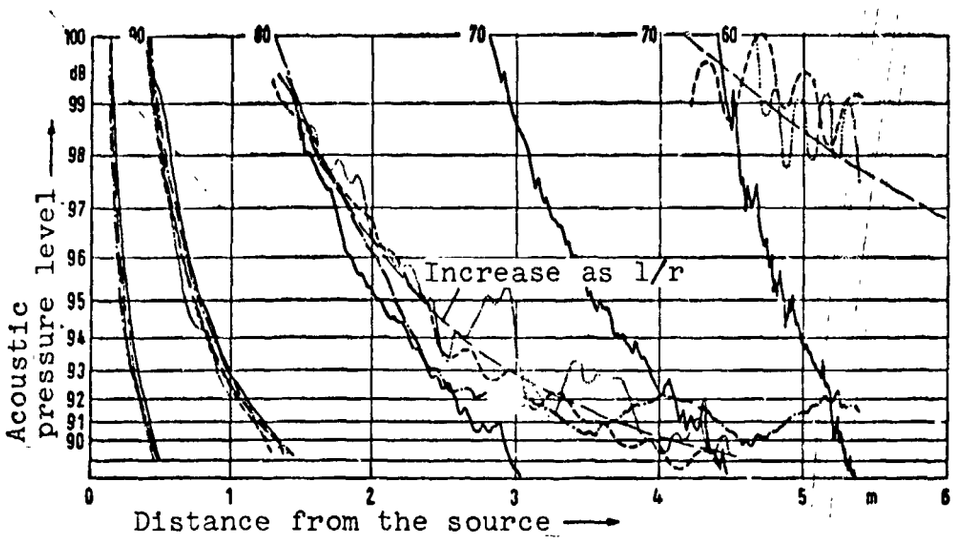

Figure 7. Continuous measurement of the acoustic pressure level along the large median JJ'

····· 1000 Hz, -·-·- 160 Hz,
– – – 500 Hz, ——— 80 Hz.

7.2 Results

We made a systematic investigation of 3 directions in a horizontal plane located 1.80 m above the ground: the small median II', the large median JJ', and the diagonal oriented towards the lock KK'. The deviations between the sonic levels measured in these three directions and the law $p \sim 1/r$ can be seen in Figures 9, 10 and 11 for frequencies between 80 Hz and 8 kHz.

According to the results obtained, we can approximately distinguish three frequency ranges:

- the range 2.5 to 8 kHz for which the measured deviations never exceed ±1 dB,
- the range 200 Hz to 2.5 kHz for which the deviations are somewhat larger, especially above 800 Hz where they can reach ±2 dB,

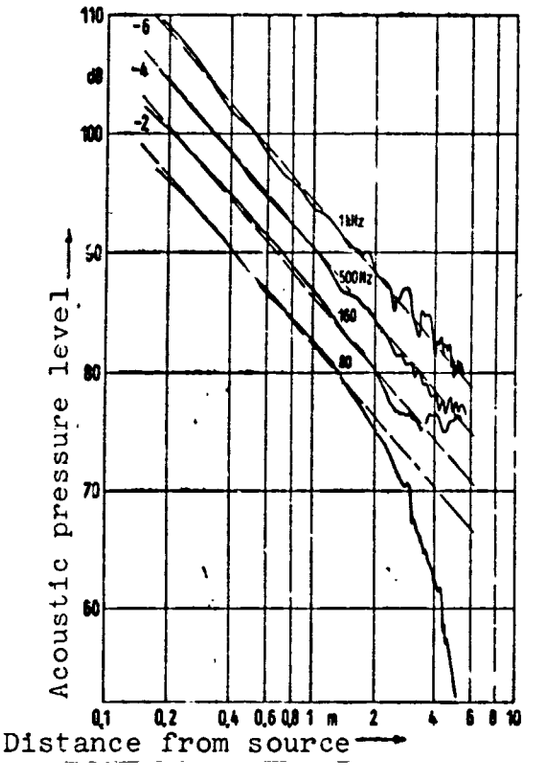

Figure 8. Graph of the decrease in the acoustic pressure level as a function of distance from the source along the median JJ' (average frequencies)

- the range 80 Hz to 200 Hz for which large deviations appear when the source-microphone distance exceeds 2.5 m.

In the latter region, the most characteristic observations are found for frequencies close to 80 Hz and 160 Hz. For 160 Hz, the deviation becomes positive and increases with distance. For 80 Hz it is negative, on the contrary. The continuous variation of these phenomena to both sides of these frequencies is translated into a variation which is much closer to the ideal case at 100 Hz and at 40 Hz (Figure 12). The similitude between /75 the results obtained in these three directions for the same

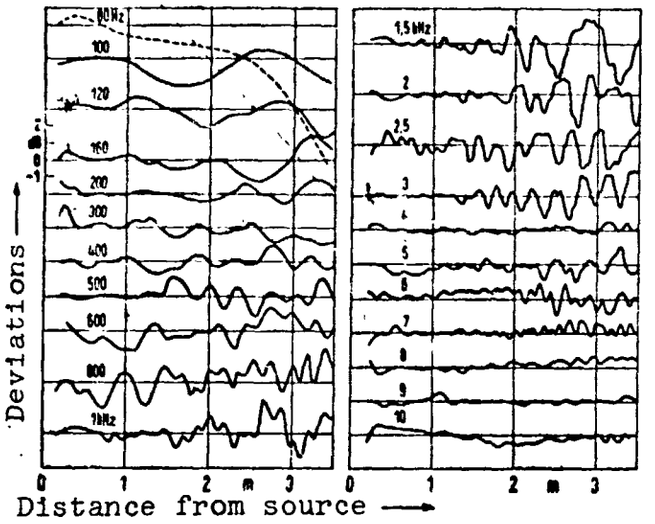

Figure 9. Deviations from the 1/r law along the small median II'

source-microphone distance leads us to believe that the deviations observed for $r \geq 2.5$ m are due to multiple reflections at the walls of the chamber, and not only two reflections along the front wall. The calculation of the amplitude of the normal reflected wave and the investigation of the acoustic field in the region at least $\lambda/4$ away from the concrete wall shows that for 80 Hz there is an increase in the pressure level in the immediate vicinity of the cover. However, this increase is much too small to explain the 16 dB deviation observed with respect to the 1/r law. We should also notice the fact that the absorption at an absorbing cover decreases with incidence angle [10].

In the range between 200 Hz and 2.5 kHz, the pressure level has a series of maxima and minima space by about $\lambda/2$. These oscillations are produced in a somewhat uniform manner over the entire investigated distance. In addition, they undergo undulations which are more or less regular, and the amplitude becomes large for $r \geq 2.5$ m. These undulations just mentioned are

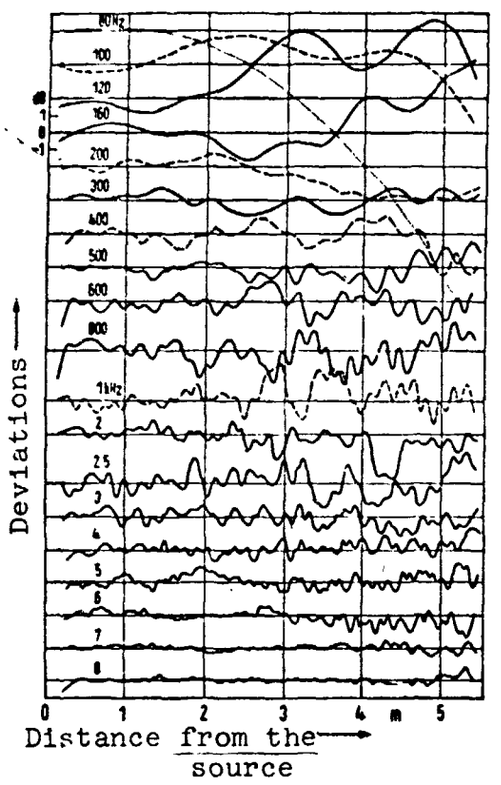

Figure 10. Deviations from the 1/r law along the large median JJ'

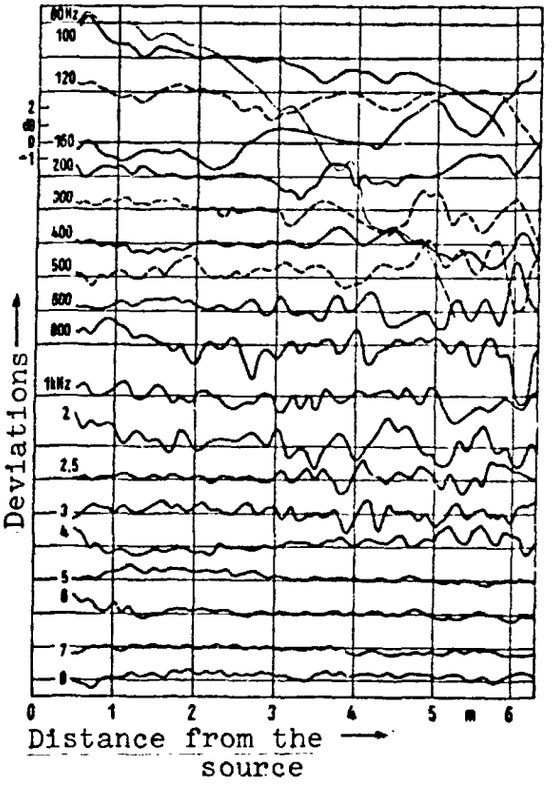

Figure 11. Deviations from the 1/r law along the diagonal KK'

responsible for larger deviations with respect to the 1/r law and seemed to be connected with the behavior of the chamber at lower frequencies. The oscillations with wave lengths corresponding to the wave length of the signal on the other hand seem to appear because of the reflection along the rear wall. They are sensitive to the mesh effect, as we were able to verify by partial additional tests.

At frequencies above 2.5 kHz, only the undulations remain but their amplitudes and average dimensions decrease.

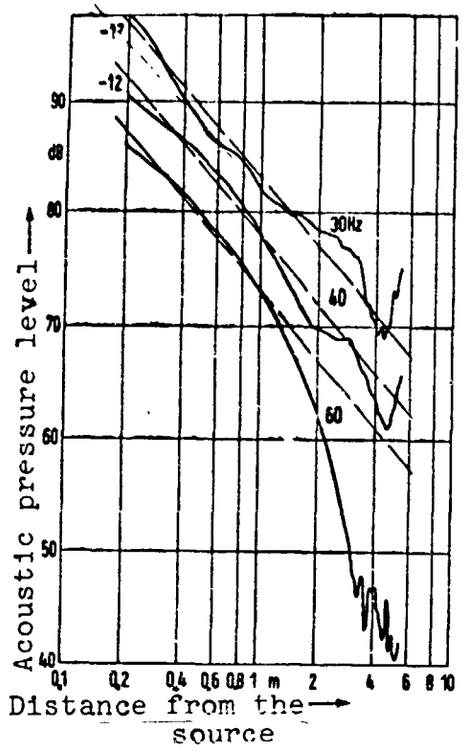

Figure 12. Decrease of the acoustic pressure level as a function of distance from the source along the median JJ' (low frequencies)

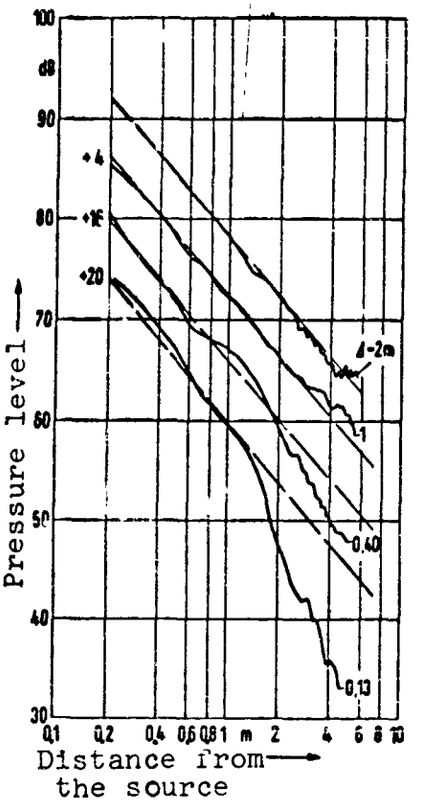

Figure 13. Variation of the acoustic pressure level as a function of distance to the source along lines parallel to the median JJ' at various distances of the cover (frequency 500 Hz)

A more exact comparison of Figures 9, 10, and 11 shows that the deviations measured along the diagonal are on the average less than those obtained for the two medians. From this fact we may conclude that the presence of the lock does not have any noticeable perturbing effect on the behavior of the chamber.

In addition to the tests described above, we also wanted to determine the minimum microphone-wall distance for which the errors are not greater than those observed along the axis. We therefore investigated lines parallel to the large median at

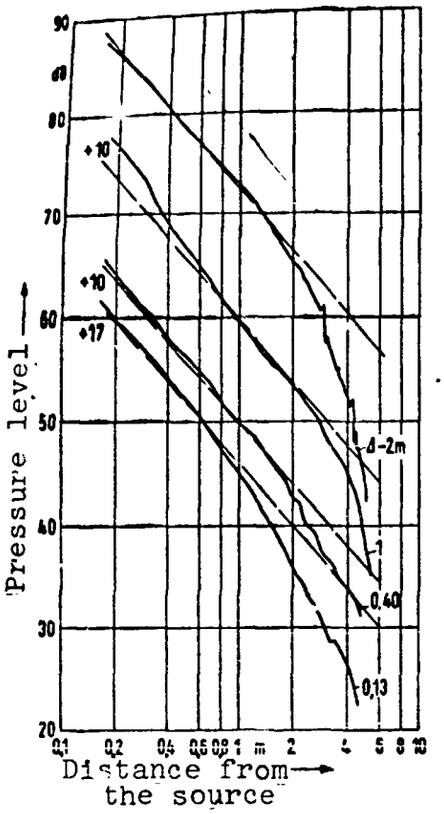

Figure 14. Variation of the acoustic pressure level as a function of distance to the source along lines parallel to the median JJ' for various distances Δ of the cover (frequency 80 Hz)

various distances Δ from the wall: 0.13; 0.40; 1 and 2 m. Figure 13 shows a variation of the measured pressure for a frequency of 500 Hz. This is characteristic of the results obtained for frequencies above about 100 Hz. The large deviations from the 1/r law were found when the tests were carried out close to the wall. For example, for Δ = 0.13 m, the deviation exceeds 2 dB as soon as r = 1.5 m. The same observations were made for the frequency 80 Hz (Figure 14) and show that the decrease of the pressure level described above is primarily located in a region which contains the major axis of the chamber.

This test series underscores the necessity for designing a covering in conjunction with the geometric characteristics of the chamber. These characteristics determine the behavior at the lowest frequencies for which the covering loses its effectiveness. The useful volume of the chamber and its performance depends greatly on the following: /77

- the prediction of the eigen modes of the chamber, for which the walls are considered to be absorbing,

- the absorbing qualities of the covering at incidence angles and at frequencies corresponding to these modes.

8. AERODYNAMIC CIRCUIT

The jet which exhausts into the anechoic chamber at the present time emerges from a circular nozzle (diameter 0.10 m) or from rectangular nozzles (dimensions 0.30 m x 0.10 m or 0.30 m x 0.15 m). The velocity can be controlled between approximately 10 to 70 m/sec.

The supply circuit essentially consists of the following:

1) An inlet collector with polyamide dust filters (Petit Therain, type P 15-500 and T 3200);

2) Two silencer elbows (Woods W B S 2 elements);

3) Three pairs of counter-rotating helicoidal ventilators (Woods 19-JAF-2022.L); the nominal rotation rate is 2900 rpm. Each ventilator can provide a flow rate of 1.25 m^3/sec at a pressure of 550 Pa.

4) A silencer 2.7 m long and with a cross section of 0.86 m x 0.74 m, containing four rock wool partitions parallel to the flow (Woods WS2 elements); the attenuation predicted by the designers is 50 dB above 125 Hz; this silencer is embedded in the wall which separates the ventilation room from the measurement room.

5) A 3 mm thick cloth connection cover;

6) Another silencer identical to the one mentioned in Section 5. It is embedded in the exterior wall of the anechoic chamber;

7) An interaction member with a section of 0.86 m x 0.74 m and a length of 0.70 m; it can support units which modify the preturbulence of the jet and which are terminated by a convergent section. The outlet cross section is a square with a side length of 0.30 m.

8) Finally, the outlet nozzles (Figure 5 b); they are connected with the convergent section mentioned previously by means of a conduit 0.80 long with a cross section of 0.30 m x 0.30 m. The outlet plane of the nozzles is 0.45 m ahead of the acoustic covering of the chamber; the entire installation is made of a damping material (1.5 mm iron tiles and viscoelastic Hoechst resin).

The jet is drawn off at the level of the wall opposing it through a mesh covered with anechoic covering material. The corresponding least dense panels were removed. Four circular openings (diameter 0.30 m) were made in the interior wall of the chamber and are connected to an exhaust circuit which essentially consists of the following:

1) A collector caisson made of concrete with a thickness of 0.10 m, attached to the interior of the chamber;

2) A wood cover (thickness 22 mm, cross section 0.84 m x 0.20 m) installed on consoles attached to the interior wall of the chamber;

3) A silencer (Woods WS2) 2 m long and embedded in the exterior wall of the chamber;

4) A helicoidal ventilator (Woods 15 JAF 1542 L or Woods 15 JAF 2022 L depending on the flow rate to be extracted);

5) A cover to the outside.

Finally three acoustical doors provide approximately 45 dB of attenuation above 125 Hz. This insulates the various rooms from the aerodynamic circuit (Figure 1).

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16. Abstract

The wall lining of the chamber consists of successive layers of glass wool panels, of densities 70 kg/m^3 and 38 kg/m^3. The former are 80 cm long, the latter, 40, 50, 60 or 70 cm long. The dimensions of the open space in the chamber are: 6.10 m (length) x 4.60 m (width) x 3.80 m (height). The acoustic characteristics of the chamber were examined by measuring the sound pressure level p as a function of the distance r from different sources. The deviations from the decay law $p \sim 1/r$ are apparent principally in the region of 80 Hz, where p decreases too rapidly, and for surveys near the walls, where the decay is frequently dependent.

An air stream is ducted into the chamber for investigations of aerodynamic noise. The dimensions of the free jet in the nozzle plane are 30 cm x 10 cm. The maximum jet velocity is 60 m/sec.

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